Estimating survival and migration rates with ultrasonic tagging

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1 Background

We have proposed to estimate survival and migration rates of late-fall-run chinook salmon and steelhead smolts from Battle Creek through the coastal ocean using ultrasonic transmitters and data-logging hydrophones. The goals are two-fold: to *describe* migration and survival rates at the scale of river reaches, and to *explain* variation in these rates. Several hundred steelhead and chinook smolts will be tagged with small, uniquely identifiable ultrasonic pingers and tracked with moored data-logging hydrophones deployed along migration corridors in the Sacramento River, Delta, Bay and coastal ocean. The proposal was among those recommended for funding in the recent CALFED Science Program PSP, albeit at a reduced amount. This brief document provides an overview of the proposal, with emphasis on data analyses. For more details on technology and justification, please contact Pete Klimley for a copy of the proposal.

Figure 1. A: Vemco V7 tag. B: Downloading data from VR2 receiver in SF Bay. Green arrow points to receiver. C: Juvenile steelhead immediately after surgical implantation of V7 tag. D: Same fish after 1 month.

2 Tagging technology

We will use Vemco V7 tags and VR2 receivers. Each V7 tag emits a series of acoustic pulses at 69kHz that are decoded by the VR2. The VR2 logs each tag code along with the time of observation. Range is on order of 300 m. Tags are implanted surgically into the peritoneal cavity of fish with fork lengths > 150 mm (Figure 1). The tagging has little effect on fish survival and swimming performance (A. Amman, unpublished data). The movement of tagged fish will be monitored by an array of VR2 hydrophones deployed along migration routes between Battle Creek and the coastal ocean (Figure 2).

3 Analysis

The goal of the work is to quantify survival and movement rates and explain any interesting variation in these rates. Figure 3 sketches out our simplified view of how movement and survival are determined. Movement rate varies due to the interaction of the animal with its environment, through its behavior. We can't observe the behavior directly (e.g., stopping to feed among emergent vegetation), only the movement rate as indicated by the time taken to pass between receivers. We hope to explain variation in movement by including readily-measured and biologically meaningful explanatory variables in a simple model of movement rate (some variables and data sources we are considering are described in Table 1). For example, we might hypothesize that fish dally in areas with lots of natural vegetation and speed through areas with armored shores. Obviously, we expect river velocity to influence movement rate, as well as time of day, and it should not be surprising if water clarity or temperature influences migration rate. We hypothesize that survival through a reach is largely determined by predation and water diversion. Other factors, such as point sources of pollutants, could

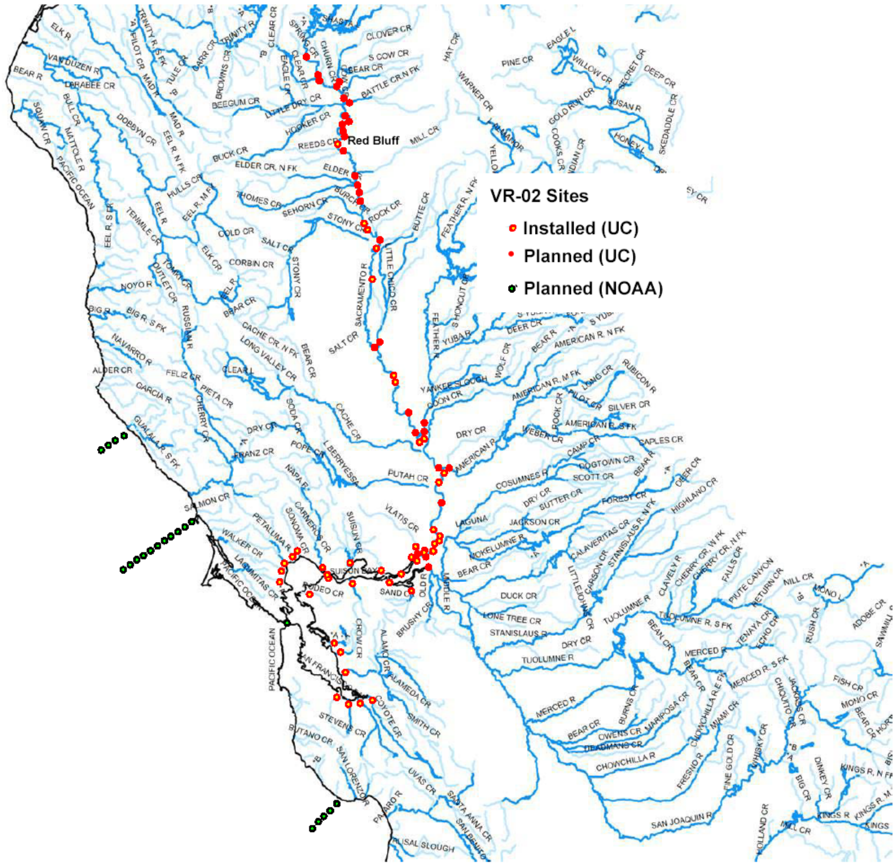

Figure 2. Map of proposed receiver locations.

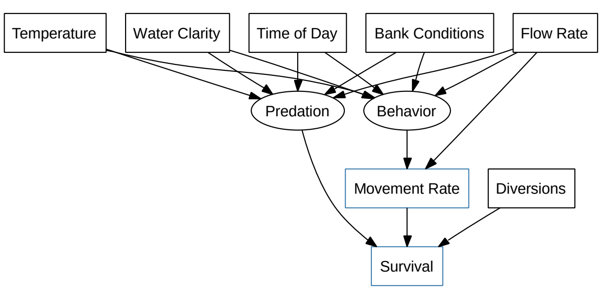

Figure 3. Conceptual model of how measurable environmental variables influence movement rate and survival rate through their influence on the behavior of the juvenile salmonids and the predators with which they interact.

also kill fish, but the effects of these might not be realized until after the fish has left the reach. The abundance and activity of predators is probably influenced by the same factors affecting the movement rate of the salmonids.

Our general approach to data analysis is to develop statistical models for the data that include explanatory variables that influence underlying mean rates (generally in a linear fashion). These models will be compared to "null" models, where rates are constant among reaches or where each reach is characterized by a unique rate. If measured environmental variables are important influences on rates, then the models including these variables should be preferred over the null models by an appropriate statistical criterion (e.g., AIC or BIC). If the null model with reach effects is best, it might be worth looking at reaches with significantly low survival rates for clues about mechanisms that aren't reflected in the environmental variables chosen prior to data collection.

3.1 Analysis of migration rates

Analyzing the migration rate data is relatively straightforward. The fundamental observations are passage times of individual fish between receivers. The migration rate of a fish through reach is simply the distance between re-

Table 1. Summary of river reach-level environmental data and sources uncovered with casual digging.

Variable	Source	Description
Water velocity	USGS	model local velocities with gage data
	various	hydrodynamic model outputs
Water temperature	UC Davis	measured by each hydrophone mooring
Riparian vegetation	CDF	25 m resolution, derived from black and white air photos and Landsat TM
	ACoE	0.6 m resolution, derived from color air photos
Rip-rap	ACoE	0.6 m resolution, derived from color air photos

ceivers divided by the time taken to make the trip. We want to know if migration rate varies among reaches, and if so, why. A null hypothesis is that migration rates are constant. We might expect, however, that migration rates are influenced by flow, time of day (or proportion of the travel time spent in darkness), shoreline conditions (e.g., amount of emergent vegetation or rip-rap), distance from the release site (perhaps migration accelerates as fish approach the ocean), temperature, turbidity, and quirks of the individual fish. The most straight-forward way to evaluate these hypotheses is to model the observed migration rates by multiple linear regression. Evidence for the significance of an effect would be a 90% confidence interval for the related parameter that did not include zero; the relative importance of different effects could be evaluated by comparing the magnitudes of the parameter estimates. An alternative linear model would use reach effects rather than covariates (i.e., each reach would be assumed to have a different migration rate).

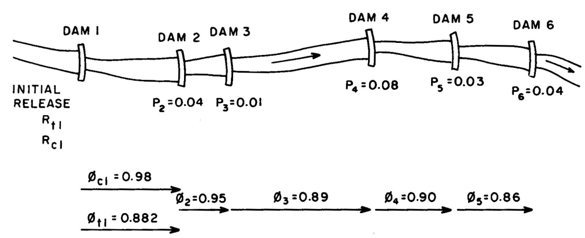

Figure 4. Schematic of the process generating release-recapture data. R fish are released at the most upstream site, and some fraction are detected as they pass dams (in this example). The number that are expected to be detected at dam i is the product of the survival rates from release point to the dam (the ϕ's), the detection probability at the dam (P_i), and the number released. From Burnham et al. (1987).

3.2 Analysis of survival rates

Analyzing survival rates is a bit more complicated, because the probability of recording the passage of a fish at some point depends on both the survival of the fish to that point and the probability that it is detected given that it survived. The data (counts of individual fish passing detection points) are viewed as arising from the combined effects of reach-specific survival probabilities and receiver-specific detection probabilities (Figure 4 shows a simplified case). The fate of individual fish can be represented by a capture history, which is simply a string of 1's and 0's indicating at which points the individual was detected. The survival and detection probabilities define a multinomial distribution for the capture histories, and these probabilities can be inferred from the observed fates of a group of tagged fish via the maximum likelihood method. The situation described in Figure 4 is modeled by the Cormack-Jolly-Seber model for live recaptures, the default analysis in program MARK. In our case, there is a slight added wrinkle caused by alternate pathways (e.g., fish can take a bypass or the mainstem Sacramento), but this does not cause conceptual problems for the analysis: one must add terms for the probability of taking alternate paths.

It is tempting to view our ≈ 70 receiver lines as the dams in Figure 2, and try to estimate the 70 or so survival and detection rates from the patterns of detections. With a few hundred fish in a release group and very high survival rates expected for such short distances, we shouldn't expect to be able to learn much about the factors controlling survival at such fine scales (because while noise if low, the signal is even lower). Instead, we will need to define longer reaches such that a significant level of mortality is observed within the reach. Without some preliminary data, we can't know what the scale of these reaches will be. Should survival rates be much lower than expected, a different problem arises: so few fish will be available at downstream sites than the precision of survival rate estimates will be poor. Should this problem become apparent, it could overcome by releasing some groups well downstream of Battle Creek.

3.3 Simultaneous analysis of survival and migration

Because migration rate can influence survival by altering the interaction of prey with their predators (Anderson et al., 2005), it would be best to model movement and survival simultaneously. This can be accomplished in a mark-recapture setting using multi-strata models. In these models, the animals move among places (river reaches) and states (live or dead). Given an animal was sighted in a particular place and time in the past, whether it is sighted in another particular place in the future depends on whether it survives the intervening time and moves among the places. We can estimate the transition probabilities (survival and movement rates) and the influences of environmental variables using the same machinery used for the CJS model.

4 Advantages and disadvantages of ultrasonic tagging

The main disadvantages of acoustic tags come from the size of the tag and the cost. The most aggressive researchers are putting V7 tags into smolts as small as 120 mm, but this still limits application. Tags must be implanted surgically, which takes much more time than injecting a full-duplex PIT tag or coded-wire tag. We note that survival experiments using acoustic tags share some difficulties with more traditional approaches including problems of tag shedding and handling effects.

Most of the advantages of ultrasonic tagging come from the ease of "recapturing" tagged individuals. At good sites, it can be easy to achieve 100% detection rates for single fish (if multiple fish are traveling together and moving quickly, it is possible for tags to interfere, allowing some of the group to pass undetected). Furthermore, the hydrophones are relatively inexpensive and can be deployed unattended for months at a time. Finally, each fish is uniquely coded, allowing individual fates to be determined and related to individual traits (including migration history). The net effect is that the movement and survival of individual fish can be followed at a very fine scale, which should make it much easier to detect the effects of environmental manipulations and gain insight into the mechanisms behind the effect.

References

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Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, & K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5, Bethesda, MD.